The Relation between Financial and Housing Wealth of Dutch Households*

by

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Abstract

We analyze households' joint investment decisions for financial wealth and homes. We use a bivariate censored regression model with endogenous switching. Fixed costs or transaction costs are captured by an unobserved nonzero censoring threshold. The model allows for spill–over effects of a binding threshold for one asset on the demand for the other asset. We find that tenure choice affects the level of financial wealth. Our results do not support the view that people first accumulate financial wealth before acquiring homes. This can be due to the absence of down payment constraints in the Netherlands.

Keywords: housing demand, household saving, portfolio choice, limited dependent variables

JEL classification: *C34, D12, G11, R21*

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1 Introduction

Housing wealth and financial wealth are the most important asset categories in households' portfolios, across all age groups and in many countries. See, among others, the descriptive studies of Alessie *et al.* (1995) for the Netherlands, Banks and Blundell (1994) for the UK, Kessler and Wolff (1991) for France and the US, and Wolff (1994) for the US. In this paper we investigate how the investment decisions for housing and financial wealth of households are interrelated.

This relationship is important for various reasons. First, as a substantial part of the wealth of home owners is held in the form of housing wealth, the home ownership decision and the amount of housing wealth will have an impact on the level and the structure of financial assets. Saving behavior of home owners will therefore differ from that of renters, and the home ownership rate may have implications for the aggregate saving rate. Moreover, house price developments or restrictions in the housing market will not only have an impact on the demand for housing but also on financial wealth holdings. For instance, as has been stressed in the recent literature, down payment constraints can influence renters' decisions to save (Engelhardt (1994, 1996), Haurin *et al.* (1996) and Sheiner (1995)).

But there is no reason to expect a one way causal relationship. Changes in the financial wealth market may also have spill–over effects on the housing wealth decisions. Financial and housing wealth are the joint outcomes of one decision process, and are therefore jointly determined.

This suggests that the two decisions should be modeled simultaneously. Theoretical models of this nature have been around since Henderson and Ioannides (1983). But in the empirical literature on household portfolio choice and home ownership and housing wealth, the joint nature of the decision has, to our knowledge, never been modeled explicitly. Most of the empirical literature on housing focuses on consumption of housing services, and neglects the investment aspect. Papers which do consider housing investment usually treat it in isolation of other investment possibilities. An exception is Ioannides (1989), where housing wealth related variables are explained from non–housing wealth variables and vice versa, but without taking account of the endogeneity in either case.

We develop an empirical model that jointly explains housing investment demand and financial wealth holdings, and that extends models used in the empirical literature on household portfolio choice (see, for instance, King and Leape (1987) or Ioannides (1989)). We estimate the model using Dutch cross section data drawn in 1988. More than half of the households in our sample do not hold any housing wealth. Also, many households report not to hold any financial wealth. Our econometric model explicitly accounts for these zero asset holdings. The model distinguishes several regimes, according to whether asset amounts are zero or not. It is similar to the demand system of Lee and Pitt (1986), which is characterized by different demand functions for each commodity, for the case that nonnegativity constraints on demands for other commodities are binding or not. Here we allow for differences between the demand for financial wealth between home owners and renters, and between the demand for housing wealth of those who do and those who do not hold financial wealth. Endogeneity of the regime choice is accounted for by analyzing the complete bivariate model.

While the model of Lee and Pitt (1986) explains zero amounts from nonnegativity constraints only, we allow for household specific thresholds which can be seen as minimum amounts of assets held. If the optimal amount is lower than the threshold, the amount actually held will be zero. An interpretation of the thresholds is fixed (transaction) costs. We estimate the model separately for gross asset amounts and for equity, i.e. amounts net of debts.

Our main findings can be compared to the recent literature on the relevance of down payment constraints for households' saving behavior (Engelhardt (1994, 1996), Haurin *et al.* (1996) and Sheiner (1995)). Due to such constraints, higher house prices could induce renters who plan to buy a house to save more in the year(s) prior to homebuying in order to meet the down payment constraint. Our findings do not support this. This may reflect the absence of effective down payment constraints in the Netherlands. We find that the prime home–buying years are roughly between 20 and 40 years of age. Comparing age patterns for home ownership and financial wealth holdings, there is no evidence that younger households hold high amounts of financial wealth at ages before they typically would buy a home. We also find that renters possess fewer financial resources than homeowners. As house prices rise, financial wealth holdings of renters decrease (while the number of renters increases). If renters were saving to buy a house, we would expect the opposite.

The interaction effects in the model imply that the demand for financial wealth of home owners differs significantly from that of renters. We have conducted simulations which show that an increase of house prices would reduce the homeownership rate accompanied by an increase in average house values for homeowners. At the same time, mortgage values would increase as well. Financial asset holdings would also be affected by a house price increase, which reduces the financial ownership rate and increases the conditional means, leading to a total additional financial accumulation.

The remainder of the paper is organized as follows. In Section 2 we sketch the organization of the Dutch housing market, which differs substantially from that in other countries. In Section 3 we summarize our data and present some prima facie evidence that asset holdings of home owners differ substantially from those of renters, even after controlling for wealth and other variables. We introduce our empirical model in Section 4 before we present results in Section 5. Section 6 concludes.

2 The Housing Market in the Netherlands

The housing market in the Netherlands is characterized by a large fraction of renters, most of whom live in rent–regulated housing. In international perspective, the homeownership rate is comparatively low. In 1990, about 45% of all households were home owners, compared to an EC average of about 62%,[1] and 64% in the US.[2] The nonprofit sector supplies 77% of rental accommodation. Private ownership of rental housing is usually indirect via institutional investors. Only 13% of all rental dwellings are directly owned by private persons.

Households with income below some threshold (depending on family composition) have preferential access to the regulated rental sector. Suppliers here are the municipal housing associations. Though these have become more independent of the government or were privatized during the past decade, the rents they charge are subject to nationwide regulations, and are much lower than the rents in the free market for similar dwellings.

Low income households are eligible for rent subsidies. The subsidy level depends on the actual rent paid, family composition, taxable household income, and age. The maximum rent subsidy decreases with family income and is zero for incomes exceeding the modal income level. See Koning and Ridder (1997) for details of the system, and for an analysis of rent subsidies on housing demand. Subsidies have been cut back in the past decade (see Van der Krabben (1995)).

The return to housing as an asset depends critically on house prices. Average real house prices have been quite volatile during the past few decades. They rose by 52% from 1976 and 1978, fell by 38% from 1979 to 1982, remained at a low level until 1985, and have been increasing since 1986.[3] Similar evidence of volatility is found in the UK (Holmans (1994)) and the US (Poterba (1991)).

Mortgages in the Netherlands are usually obtained from banks. The bank's decision is on whether or not to offer a mortgage contract, and on the maximum amount. The system does not know explicit uniform down payment constraints, but most banks use similar criteria for evaluating mortgage applications. These criteria mainly relate to the default probability and to the value of the mortgage relative to the value of the house. Thus current income matters, but also expected future income, and whether the head of the household has a permanent job or not. If families can partly finance their house with savings, banks are more inclined to offer a mortgage contract, because the collateral value of the house is relatively higher. In many cases, for inexpensive houses and household heads with tenured jobs, the default risk is covered by the municipality. In these cases, the interest rate is usually lower than in other cases. Often, prospective home owners

[1] This is the 1991 average of home ownership rates in 12 EC countries (excl. former East Germany), weighted by total dwelling stock; source: European Commission.

[2] This refers to 1989; see Holmans (1994).

[3] Van der Krabben (1995).

can obtain a mortgage loan covering 100% (or even more) of the value of the house. Mortgage interest rates were at a minimum in 1988. In the same year, the number of newly registered mortgages reached a maximum (Van der Krabben (1995)).

User costs of homeownership and returns to housing assets and financial assets also depend on the marginal tax rate faced by the main earner in the household. The Netherlands have an individual based progressive income tax system. The marginal rate in 1988 as a function of taxable income is piece–wise constant in nine brackets, with a maximum of 72%. The tax–free allowance depends on household composition. In addition, there are tax–free amounts on interest from savings and on dividend income (Dfl. 1000 each for individuals; Dfl. 2000 each for couples). Interest payments on mortgages and consumer credits are fully deductible from the income tax base. Capital gains (both realized and unrealized) are tax–exempt. Home owners have to add a virtual rental income component depending on the value of their house to their taxable income, but this is a relatively small amount. All in all, the income tax rules make it attractive to invest in housing for households with a high marginal income tax rate.

In addition, there is a municipal tax on housing property (about 0.28% per year of the value of the house), and a tax on wealth exceeding some minimum threshold. The latter tax makes it more attractive to invest in owner occupied housing than in financial wealth, since only 60% of owner occupied housing wealth is taxed.

The institutional factors in the Netherlands thus create incentives in the same direction: renting is more attractive for low income households (access to the regulated rental market and rent subsidies), while home ownership is mainly stimulated for high income groups (tax rules, mortgage access).

3 Data

The micro data we use in the analysis stem from a survey conducted in 1988 by a group of Dutch banks (Dutch Collective Bank Study, CBO). It comprises 10113 individuals in 3704 households. The survey is targeted at the financial structure of household and individual wealth and at the relationships between consumers and banks or other financial intermediaries. It is designed to be representative of the Dutch population in terms of socio–demographic characteristics. Like most other household surveys, it appears to suffer from underreporting on asset amounts. Yet, it resembles national figures on financial wealth better than comparable Dutch sources, in particular with respect to ownership rates (see Alessie *et al.* (1993)).

The survey questions are asked to all household members aged 18 and above. We aggregated the individual responses over all assets within each asset category and over all respondents per household. Due to missing values or severe outliers in the explanatory variable on net monthly income, we had to discard 627 households. The marginal income tax rate is constructed from income, family composition, and labor market status variables. We also include the maximum rent subsidy, constructed from family composition and income. Other background variables pertain to age and family structure, employment status, and a regional house price index. The latter is based on average regional selling prices of houses, provided by the Dutch Association of Real Estate Agents. We differentiated according to the type of dwelling and divided the regional prices by national averages.[4] Missing information on the variables for the degree of urbanisation reduced the sample size by another 189 observations to 2888. An overview of the explanatory variables is given in Table 1.

Table 1 about here

The survey contains questions on ownership of single asset units, and on amounts (conditional on ownership). While nearly all households provided information on ownership, information regarding the amounts is often missing (see Table 3 below). The questionnaire comprises detailed information on general financial behavior, saving accounts, checking accounts and credit cards, stocks, bonds, loans, mortgages, and insurances. Only information on transferable wealth is asked; pension and social security wealth cannot be recovered from the data. Moreover, there is no direct information on amounts in checking account balances, capital accumulation in life insurances, or values of major durables. Thus, total household wealth is not observable.

We do not observe variables related to the quality or location of one's home. The data neither distinguish between owner occupiers and landlords, nor do they provide information on rents paid by tenants or rental income of landlords. These limitations do not hamper the analysis of housing as part of the portfolio allocation, though they limit a specific study of housing consumption.

Housing equity is constructed as the difference between the self–reported value of the home and the outstanding mortgage debt. For some types of mortgage (linked to life insurances), an outstanding debt was imputed using other mortgage information (127 observations). Some negative values of housing equity were set to missing since they seemed implausibly high (121 observations where the initial mortgage is more than 20% higher than the current value of the house).

Similarly, we consider both financial assets and financial equity. The latter is defined as financial assets net of liabilities, excluding mortgage debt. Financial assets comprise saving accounts, time deposit accounts, saving certificates and certificates of deposit, shares in domestic and foreign companies, shares in investment funds, options, bonds, and mortgage bonds. Of all households in the sample, 15.7% have financial debt as well as a positive amount on their saving account. Only 3.2% have financial debt and zero holdings in financial assets. Financial asset holdings and liability holdings are virtually

[4] See Polinsky and Ellwood (1979) for an empirical justification of using regional prices.

uncorrelated (correlation coefficient of -0.011). Only 6.3% of all households hold stocks or bonds, most of them in combination with other, saving related assets.

Table 2 about here

Table 2 contains summary statistics of financial and housing assets and equity (missing values excluded). The means suggest that housing assets are more important for the aggregate composition of wealth than financial assets, in spite of the higher ownership rate for the latter. The distribution of financial assets is strongly skewed to the right. This suggests that a log transformation may be helpful to obtain an empirical model (with normally distributed errors) that fits the data.[5] We shall come back to this in Section 5.

Figure 1 about here

Nonparametric density estimates of the marginal distribution of the log transformed variables on housing and financial assets and equity, excluding zero–observations, are provided in Figure 1. While the distributions of the asset variables are not far from normal, those of the equity variables are bimodal, with one positive and one (smaller) negative mode.

Table 3 about here

Table 3 provides an overview of the numbers of positive, zero, and missing amounts. 89% of the households hold housing or financial assets, 85% hold financial assets, 50% invest in housing, 46% in both. Figures for variables including housing and financial debts are similar. For 19.3% of home owners and 14.2% of financial equity owners, the amount is not observed. The numbers of missings are substantial, and ignoring them may seriously bias the results. We take account of this in the model in Section 4.

Figure 2 about here

Figure 2 shows kernel regression estimates of ownership rates as a function of age of the head of the household for financial assets, liabilities, homes, and mortgages.[6] The picture displays the cross–sectional age profiles, which do not necessarily reflect life cycle effects. Ownership of financial assets is widespread across all age groups. Only old age households are less likely to possess financial assets. The home and mortgage ownership

[5] To be precise, throughout the paper we use the following sign preserving log transformation:

$$x \mapsto g(x) = \begin{cases} \ln(x+1) & \text{if} \quad x \geq 0 \\ -\ln(-x+1) & \text{if} \quad x < 0. \end{cases}$$

[6] All our kernel regressions use a Quartic kernel, and uniform (nonadaptive) bandwidth = 11.

rates are hump shaped and peak in the age group 35 to 50. Before age 40 almost all home owners also have a mortgage. Elderly households are less likely to hold mortgage debt, whereas their home–ownership rate is still high. They have not completely liquidated housing equity. Ownership rate patterns for financial liabilities are similar to those for homes, albeit on a lower level.

Figure 3 about here

Figure 3 shows kernel regression estimates on age of the total value of the home, the total value of financial assets, home equity (ie. net of mortgages), and financial equity (assets net of liabilities).[7] For the sample as a whole, the pattern of housing assets is hump shaped with a maximum at age 45. Due to falling mortgage debts, however, housing equity falls less steeply at higher ages. Financial assets and financial equity are close to each other and increase with age. This shows that although many young and middle aged households hold some financial debt, these debt holdings are not substantial. In comparison with the ownership patterns, households in the old age group households tend to be less inclined to hold financial assets, but if they do, they hold substantial amounts.

Figure 4 about here

Figure 4 splits wealth holdings by tenant status. Comparing it with Figure 3 shows that the hump shaped age pattern of homeowners' house values is mainly due to ownership rates. Yet, homeowners in their 50s tend to have the most valuable houses. Homeowners hold more financial assets than renters at almost all ages, and most prominently at old ages. There is no evidence of saving for a down payment: we neither observe that young renters hold particularly high levels of financial wealth, nor that young homeowners hold comparatively low levels of financial assets.

Are homeowners different? Is portfolio behavior of households who own their home different from that of renters, given total wealth? To answer this question, we estimated (univariate) probits for ownership of various types of assets and debts, conditioning on home ownership, total wealth and other background variables. The four asset types considered are short term savings (saving accounts), long term savings (e.g. time deposit accounts and saving certificates), life insurance contracts, and stocks or bonds. We also used an ordered probit model for the number of asset types held.[8]

We found that homeowners hold significantly more types of financial assets than renters, even after controlling for wealth and other characteristics. The homeownership

[7] Observations with zero holdings of the assets are included; observations for which the amount is missing are not.

[8] 42% of the 2888 households hold one and 41% hold two of the four financial asset types while 10% hold none.

dummy is significantly negative in the equation for short term savings, insignificant only in the stocks and bonds equation, and significantly positive in the other asset ownership equations and in the equation for financial debts. These regressions do not have a structural interpretation, since home ownership and asset ownership will be jointly determined. In the remainder of the paper we will therefore focus on setting up and estimating a model for the joint determination of investment in financial and housing assets.

4 Model

Henderson and Ioannides (1983) have developed a stylized theoretical model which illustrates the relation between the economic decisions related to housing consumption and housing and financial investment. Their model explains the role of variables like house prices, or tax rates. It assumes that a representative household maximizes utility over two periods, and derives utility from the two commodities housing and non–housing. The household can invest its savings in housing wealth or financial assets, and can finance part of its housing wealth by a mortgage loan. Part of the housing stock corresponding to housing wealth can be owner occupied, the remainder can be let to others.

Prices, tax rules, interest rates, etc. enter this model in various ways. For different versions of the model, various authors have looked at comparative statics. In principle, for a given functional form and given details of the tax system, etc., the model can be solved. Many complications arise, however, if it is to be used to construct a structural empirical model: the time periods are not well defined, initial wealth, future income, (expected) returns are unobserved, the tax rules are complicated and lead to nonconvex budget sets (see Section 2), etc. Moreover, our data are not rich enough to identify housing consumption (see above). Our data also show that many people hold financial debts as well as saving accounts, which is not explained by the theory. Furthermore, the theoretical model does not allow for fixed costs of house ownership, while in empirical models it appears to be important to disentangle the ownership from the amount decision. Therefore, our empirical model does not incorporate the full structure of the theoretical model, although it does account for the bivariate nature of the financial decision making process and incorporates price and tax rate effects.

We separately consider two models: one explaining housing and financial assets, the other housing and financial equity. In both cases, we use the same type of model. Following the Henderson and Ioannides (1983) framework, suppose a household can allocate its budget in three ways: financial wealth, housing wealth, or otherwise (other consumption, durables, etc.). The optimal allocation will depend on future expectations, tax rules, preferences, etc. The unrestricted allocations to the three options can be compared to notional demands in a demand system with three goods. If one or more restrictions become binding, notional demand has to be replaced with conditional demand, and the form of the optimal allocation function will change. This is the spill–over effect from the restriction on one good on consumption of other goods. See, for example, Lee and Pitt (1986) for the case of binding nonnegativity constraints: if one nonnegativity constraint is binding, the notional demand functions for the other goods will be replaced with conditional demand functions given zero consumption of the good for which the constraint is binding. These conditional demand functions can be written in terms of the notional demands. In the case of a linear expenditure system, for example, the conditional demand for one good is a linear combination of the notional demand functions for all goods.

We exploit this idea to formulate a censored regression model with endogenous regimes, in which the allocation into housing wealth depends on whether financial wealth is held, and vice versa. Instead of nonnegativity constraints, we work with unobserved stochastic censoring thresholds, that make the model more flexible (see Nelson (1977) for the univariate case). Such thresholds can reflect minimum purchase requirements or fixed transaction costs, for instance. Apart from costs that are linked to the purchase of a home (search costs, legal costs, real estate agent fees and other duties), fixed costs of moving will contribute to the illiquidity of housing wealth. These costs also comprise a psychological component which may depend on age and other household characteristics. Positive thresholds imply that, once a purchase is made, some minimum amount is bought.

The complete model is as follows. We start by specifying 'notional' demand equations y_i^*, and associated thresholds T_i^*, $i = 1, 2$:[9]

$$y_i^* = x\alpha_i + \epsilon_i \qquad (i = 1, 2) \tag{1}$$

$$T_i^* = x\delta_i + u_i \qquad (i = 1, 2) \tag{2}$$

Here y_i^* is notional demand for housing ($i = 1$) or financial ($i = 2$) wealth, not accounting for any constraints. x is a vector of observed explanatory variables, including, among others, income, marginal tax rate, and the house price (see Table 1). The error terms ϵ_i and u_i account for unobserved heterogeneity.

'Conditional' demand for housing ($\tilde{y}_1$) and financial ($\tilde{y}_2$) wealth are defined by

$$\begin{aligned} \tilde{y}_1 &= y_1^* + \lambda_1 y_2^* \\ \tilde{y}_2 &= y_2^* + \lambda_2 y_1^* \end{aligned} \tag{3}$$

The relation between conditional and notional demand is the same as in a linear expenditure system. They coincide if and only if the notional demand for the other asset is exactly zero.

The thresholds for the conditional demands are modeled in the same way:

$$\begin{aligned} \tilde{T}_1 &= T_1^* + \lambda_1 T_2^* \\ \tilde{T}_2 &= T_2^* + \lambda_2 T_1^*. \end{aligned} \tag{4}$$

[9] The index i denotes the asset types. For notational convenience we do not carry through a household index in the derivation of the model.

It is not intuitively clear why the same λ_1 and λ_2 must be used here as in (3). For example, we could instead use $\tilde{T}_1 = T_1^*$ and $\tilde{T}_2 = T_2^*$. In Appendix A however, we show that this generally leads to an incoherent model, i.e. to a model that is not well–defined in the sense that endogenous variables are not uniquely determined for given values of exogenous variables and error terms (see Heckman (1978)), for example). Thus specification (4) is motivated by the requirement of coherency.

Whether or not financial or housing assets are held, depends on whether notional or conditional demands exceed the corresponding thresholds. This can be written as a selection mechanism, using $S_i^* = y_i^* - T_i^*$ and $\tilde{S}_i = \tilde{y}_i - \tilde{T}_i, \quad (i = 1, 2)$. The selection equations can be written as

$$\begin{array}{rclcll} S_i^* & = & y_i^* - T_i^* & = & v\zeta_i + \nu_i & (i = 1, 2) \\ \tilde{S}_i & = & \tilde{y}_i - \tilde{T}_i & = & S_i^* + \lambda_i S_j^* & (j = 2, 1) \end{array} \tag{5}$$

The model is completed by adding the regime allocation rules, which determine the observed amounts of housing and financial wealth y_1 and y_2:

$$\begin{array}{ll} (a) & S_1^* > 0, S_2^* > 0 : \\ & y_1 = y_1^*; \qquad y_2 = y_2^* \\ & \\ (b) & \tilde{S}_1 > 0, S_2^* < 0 : \\ & y_1 = \tilde{y}_1 = y_1^* + \lambda_1 y_2^*; \qquad y_2 = 0 \\ & \\ (c) & S_1^* < 0, \tilde{S}_2 > 0 : \\ & y_1 = 0; \qquad y_2 = \tilde{y}_2 = y_2^* + \lambda_2 y_1^* \\ & \\ (d) & \tilde{S}_1 < 0, \tilde{S}_2 < 0 : \\ & y_1 = 0; \qquad y_2 = 0. \end{array} \tag{6}$$

Regimes $(a) - (d)$ correspond to the entries in Table 3. The model reduces to the model with nonnegativity constraints if (with probability one) $T_i^* = 0, \; i = 1, 2$. Unlike the model with nonnegativity constraints only, our specification allows for separation of the ownership and the investment decision. This may be important if higher house prices decrease the tendency to own but at the same time raise housing wealth for those households who have chosen to own (see Haurin *et al.* (1996)). Likewise, the discrete ownership decision and the conditional continuous investment decision for financial wealth are disentangled.

We assume that the four error terms in the model are jointly normal and independent of the regressors. The variances of ν_1 and ν_2 are normalized to 1. The general model with a full covariance matrix is only identified due to functional form and distributional assumptions. We therefore identify the model by imposing exclusion restrictions on the notional demand equations.

To estimate this model, we have to guarantee that it is coherent. In Appendix A we show that this is the case if $\lambda_1\lambda_2 \leq 1$. Thus in this censored regression model, coherency does not require limiting the support of the distribution of the error terms, as it would in a simultaneous binary choice model (see Bresnahan and Reiss (1991), for example).

The empirical model described so far does not account for item nonresponse on the amount invested in housing or financial wealth. As we have seen in Table 3, however, the data are characterized by a large number of observations for whom we know that housing or financial wealth is nonzero, but for which the amount is not known. Simply deleting these observations would lead to inconsistent estimates, due to selection on the basis of endogenous variables: observations with $y_1^* < T_1^*$ or $y_2^* < T_2^*$ would be deleted with some probability, other observations would always be included.

We could model whether or not a nonzero amount of asset type i was observed by specifying a set of equations like

$$D_i^* = z\beta_i + u_i, \qquad i = 1, 2. \tag{7}$$

- If, according to (6), $y_i = 0$, or if, according to (6), $y_i \neq 0$ but $D_i^* > 0$, then y_i is observed.
- If, according to (6), $y_i \neq 0$ and $D_i^* < 0$, then y_i is not observed.

We assume that u_1 and u_2 are independent of the other error terms in the model, and that the parameters β_1 and β_2 are not related to the other parameters in the model. Under these assumptions, the log–likelihood contribution can be written as the sum of a function of the parameters in the model of interest, excluding the auxiliary parameters β_1, β_2 and the parameters determining the distribution of u_1 and u_2, and a function of these auxiliary parameters. This essentially implies that Maximum Likelihood estimates the parameters of interest and the auxiliary parameters separately, so that we can ignore the auxiliary equation for estimation of the parameters of interest.[10] The assumption that u_1 and u_2 are independent from the other errors in the model will be maintained throughout the paper. Relaxing this would require too much from the data and the optimization routines.

5 Empirical Results

We separately consider the model for assets and equity variables. The models are estimated by Maximum Likelihood. For each asset, we distinguish three cases: the amount

[10]For example, the likelihood of an observation with $y_1 \neq 0$, observed, and $y_2 \neq 0$, missing, can be written as $\Pr[D_1^* > 0, D_2^* < 0]\ f(y_1) \Pr[y_1^* > T_1^*, T_2^* < y_2^* | y_1^* = y_1]$, where f denotes the density of y_1^* (both density and probabilities are conditional on x). The first factor is a function of auxiliary parameters only, the remaining factor only involves parameters of interest. Observations in other regimes lead to similar expressions.

is zero, the amount is nonzero and observed, or the amount is nonzero and missing (i.e. only ownership information is available). This leads to nine regimes in the likelihood corresponding to the four regimes in (6) (see Table 3). Details on the likelihood function are available upon request from the authors.

We do not have strong a priori reasons to prefer a specification where dependent variables are measured in currency units over a specification with a log transformation. Instead, we select the specification which gives the best fit to the data, using Vuong's (1989) tests for nonnested models. The tests lead to the conclusion that specifications in logs give a better fit to the data, for the asset as well as the equity variables.

For nonparametric identification, we need exclusion restrictions on the demand equations for both assets (α_1 and α_2 in (1)). A natural candidate, at least for the house ownership decision, is the maximum rent subsidy. The subsidy level will affect the choice between renting and owning, but becomes irrelevant once the choice to own is made. A second candidate is current income. It can be argued that, conditional on the marginal tax rate and other covariates like education and age, current income should not play a large role in the demand for the two assets. Third, the degree of urbanization may affect the home ownership decision due to the lack of supply of rental accommodation in larger cities, but there is no reason why it should affect the demand for financial assets. Since the exclusion restrictions are open to debate, we based our preferred specification on tests, starting from the most general model.

We estimated various specifications for the models explaining the asset variables. The maximum rent subsidy was found to be insignificant in both demand equations, which justifies excluding it from the demand equation. We also found that the income variables were jointly insignificant in the demand for housing assets, while the degree of urbanization dummies were insignificant in the demand for financial assets. In our preferred specification, we therefore also excluded these variables from the respective demand equations. The results for the specification for the asset variables thus obtained are presented in Table 4. Table 5 presents the results for the preferred model for the equity variables. We have estimated a number of alternative specifications whose results will serve as sensitivity checks. These results will not be presented in detail, but will briefly be referred to in the discussion. We will focus on the most interesting effects: marginal tax rates, maximum rent subsidies, age patterns, housing prices, and spill–over effects.

Tables 4 and 5 about here

The marginal tax rate has a significant positive effect in the home ownership (selection) equation. This reflects the tax favored status of home ownership versus renting. On the other hand, the marginal tax rate is insignificant for the amount of housing assets held. These same results are found when income variables are included in the demand equations, and when equity instead of asset variables are modeled (see Table 5).

For financial assets, we find the reverse: an insignificant (positive) effect on the probability of ownership, but a significant positive effect on the amount. Interestingly, the latter effect turns smaller and insignificant if we consider financial assets net of debts. The income tax rules stimulate having (a limited amount of) financial assets and debts at the same time, and apparently the two effects cancel.

The maximum rent subsidy has the expected negative effect on the decision to own: families who can get a higher rent subsidy have a larger tendency to rent. The same variable has an even stronger negative impact on the decision to hold financial assets. Apparently, those who can get a high rent subsidy have a smaller tendency to save. This could be the case because these families have a smaller incentive to save for buying a house.

To get some idea about the size of these effects, we used model simulations. For 23.3% of all families, family income is so low that the maximum rent subsidy they can get is nonzero. Increasing their maximum rent subsidies by 10% would reduce the home ownership rate as well as the financial wealth ownership rate in this group by about 0.3%. Thus the effect is statistically significant, but economically not very meaningful.

We include a linear spline in age. The age patterns we find are in line with those in Figure 2. Comparing age patterns for home ownership and financial wealth holdings, we find no evidence that younger households hold high amounts of financial wealth at ages before they typically would buy a home. This may reflect the absence of effective down payment constraints. This finding is robust for the chosen specification, and is also obtained for the equity instead of the asset variables.

The probability of home ownership is lower in regions where housing prices are higher. This effect of the house price is significant at the 10% level in all specifications, though insignificant at the 5% level in some specifications.[11] On the other hand, conditional on ownership, the amount of housing assets increases with the price of the house. This is in line with the findings of Haurin *et al.* (1996). An interpretation is that households are discouraged from investing in houses where house prices are high, but once they have chosen to do so, they need to invest more.

Simulations using the estimated model show, that a 10% increase of house prices would reduce the homeownership rate by 2.4% (1.2 percentage points). The average amount of housing assets of homeowners would increase by 4.6%. Thus the total amount of housing assets would increase by about $4.6 - 2.4 = 2.2\%$.

If equity instead of assets are considered, the effect of house prices on housing selection remains, but the effect on the amount invested in housing disappears. This cannot be

[11] It would have been closer to economic modeling, if we had included the relative price of owning versus renting. Lack of comparable data on regional rent levels prevented us from doing so. But due to the fact that a large part of the rental market is regulated with rents based on uniform national rules, we would not expect this to lead to very different results.

explained by the discouraged investor's argument. Higher house prices apparently also lead to higher mortgages. This is in line with the fact that the maximum mortgage one can get depends on the value of the house.

The house price has a significant negative impact on the probability of holding financial wealth. For renters, this might mean that higher house prices discourage saving for a house. For owners, it may simply mean that higher house prices make it more attractive to hold all wealth as housing wealth. Conditional on holding financial wealth, on the other hand, the effect of the housing price on the amount of financial assets is positive. This may mean that renters who have decided to save for a house, save more if houses are more expensive. Thus the total effect of house prices on financial assets would be ambiguous: fewer people hold financial wealth, but those who do hold more. This reflects an important source of heterogeneity of savings behaviour.

Simulations for the assets model show that a 10% house price increase would reduce the financial ownership rate by 1.8% but would increase the financial asset holdings of those who own financial assets by about 5.3%. Thus the total level of financial assets would increase by about 3.5%.

The effect of the housing price on the conditional demand for financial equity, however, has the opposite sign, though it is insignificant at the 5% level. Apparently, higher house prices lead to higher financial assets for some people, but to higher financial debts as well. We have no good explanation for this, since it is not clear why higher house prices should stimulate both financial assets and financial debts.

Apart from the impact of housing prices, our model also allows for an interaction between the two assets through the parameters λ_1 and λ_2, which refer to the impact of binding thresholds (equation (3)). While λ_1 is significantly positive, λ_2 is negative but insignificant at all conventional levels. The coherency condition for the empirical model is amply met. A positive value of the λ_1 implies that the two types of assets are substitutes: if the optimal level of financial wealth is positive but, due to the threshold constraint, financial assets are not held, this will increase the demand for housing assets. On the other hand, if people are forced to rent while the optimal level of housing assets y_2^* is positive, this reduces the demand for financial wealth. This is not in line with the idea that financial assets are mainly held to finance down payments for a future house purchase. It should be noted, though, that the size of both λ_1 and λ_2 is small, so that the economic significance of these spill–over effects is limited. Moreover, while the sign of both λs remains the same, the significance levels vary substantially across specifications.

If we consider equity variables instead of assets, the estimate of λ_2 is significantly negative and large compared to the assets case (-0.096 with $t-$value -2.84), implying that the spill–over effect from housing to financial equity is larger than for the gross asset amounts. Thus people whose desired housing equity is positive but too small so that they rent instead, also have lower financial equity than similar people who own a house. In a sense, this means that housing and financial equity are complements. The estimate of λ_1 is virtually equal to zero and insignificant at all conventional levels.

Other demographics and other socio–economic variables are included for various reasons. First, some variables proxy total lifetime wealth (education level, type of employment, marital status). Second, some demographic variables may have a direct impact on housing demand. The estimates by and large confirm our expectations based on other studies in the field.

We have checked the fit of the models by comparing simulated and actual sample means and housing and financial wealth ownership rates.[12] We find that the model captures the ownership rates and the correlation between holding financial and housing wealth quite well. The models for assets are able to capture the mean asset levels rather well. For the equity variables, the fit is less. This may be due to the bimodal nature of the distribution of the equity variables (see Figure 1). Partitioning the sample by income quintile leads to the same conclusions: the model for assets fits the data reasonably well, but for the equity variables there are some substantial deviations between predicted and actual conditional means.

6 Conclusions

This paper has presented an empirical model for households' joint demand of financial and housing wealth, the two most important categories in household assets. We have considered both the amounts of assets held, and the amounts net of liabilities and mortgages (equity). The model is of a bivariate censored regression type with endogenous switching, enhanced by two threshold equations which have to be overcome before investments are made. The model has been estimated on a representative sample of Dutch households, including both renters and home owners and both financial asset holders and nonholders. We allow for spill–over effects between asset demands, when one of the assets is not held.

The main finding is that demand for financial wealth for home owners and for renters is systematically different, while housing wealth is not affected by whether or not financial wealth is held. Consistent with previous studies in this field is the finding that higher regional house prices reduce the likelihood of homeownership. At the same time, housing wealth of home owners responds positively to house price variation, whereas it does not affect their housing equity. Higher house prices also decrease the probability of holding financial wealth, whereas they increase the conditional demand for financial assets but have an insignificant effect on conditional demand for financial equity.

As has been widely discussed in the recent literature, down payment restrictions operate like certain liquidity constraints and influence households' saving behavior (cf. Engelhardt (1994, 1996), Haurin *et al.* (1996), and Sheiner (1995)): both in Canada and

[12] Details are available upon request from the authors.

in the U.S. a down payment is specified as a percentage (usually in the range of 5–25%) of the purchase price of the house, such that an increase in house prices can lead to a higher down payment and thus can induce higher saving. On the other hand, if those increased down payments are too high, renter households might become discouraged from buying a house at all or be willing to only buy a smaller house to compensate for the increase in down payments, or even to delay the date of home buying. A higher down payment amount implies a greater intertemporal distortion of the consumption plan such that the discounted benefits of homeowning might fall short of the discounted costs of consumption distortion (cf. Artle and Varaiya (1978) for a theoretical exposition). Thus, both timing and extent of preownership saving are affected. In the Netherlands however, the low homeownership rate and the effective absence of down payment constraints imply that this type of liquidity constraints are not of major importance for Dutch households' saving behavior. This presumption is corroborated by our empirical findings.

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Tables and Figures

Table 1: Summary Statistics of Exogenous Variables (2888 observations)[a]

Variable	mean	stdv.	min	max	median
ln(income+1)	7.739	0.675	0	11.495	7.753
age of head	43.937	15.286	18	89	40
ln(max. rent subsidy+1)	1.761	3.212	0	8.425	0
marg. tax rate	0.474	0.133	0	0.72	0.51
interm. education	0.326	0.469	0	1	0
high education	0.159	0.365	0	1	0
self–employed	0.105	0.306	0	1	0
white collar	0.449	0.498	0	1	0
other occupation	0.199	0.399	0	1	0
part–time	0.050	0.218	0	1	0
other status	0.347	0.476	0	1	0
female	0.202	0.401	0	1	0
couples	0.700	0.458	0	1	1
divorced / widowed	0.163	0.370	0	1	0
no. children	0.984	1.122	0	8	1
house price index	0.963	0.154	0.626	1.230	0.982
bigger cities	0.222	0.416	0	1	0
smaller cities	0.200	0.400	0	1	0
country towns	0.416	0.493	0	1	0
country side	0.124	0.330	0	1	0

[a] *Definition of variables:* income: sum of net labor income (Dfl/month) of head and partner; (7 households report zero income); in the regressions we employ a linear spline in ln(income+1) with knots at income levels Dfl. 1200 and Dfl. 4400; age: in the regressions we employ a linear spline with knots at ages 35 and 45; max. rent subsidy: is the maximum annual subsidy a renter household could obtain, given their age, family status, and gross income; marginal tax rate: calculated from individual net earnings and family composition; the household rate is set equal to the maximum of the two individual rates; the house price index is based on average regional selling prices of houses, provided by the Dutch Association of Real Estate Agents (we differentiated according to the type of dwelling and divided the regional prices by national averages); the remaining variables (except for the number of children) are dummies: intermediate education: technical and vocational training for 16+ years old, and preuniversity education; high education: university degree or higher vocational training; labor supply: part–time employment (10–35 hours per week); other status: disabled, unemployed, retired, students and housewives/men without alternative occupation (reference group is full–time (36 hours per week or more)); occupational status: self–employed (includes free lancers, directors or owners of firms, farmers or market gardeners), whitecollar employees and other occupation (people without paid employment and others); reference group is bluecollar workers; couples: married or living together; urbanisation: (reference group: the three big cities Amsterdam, Rotterdam, The Hague).

Table 2: Summary Statistics of Endogenous Variables (2888 observations)

Variable	nobs.	mean	stdv.	min	max	median	skewn.
house value	2866	79.59	99.59	0	850.00	0	1.55
zeros excluded	1413	161.43	83.09	10.00	850.00	145.00	2.40
log house value	2866	5.85	5.95	0	13.65	0	0.04
zeros excluded	1413	11.88	0.51	9.21	13.65	11.88	–1.13
fin. assets	2573	16.53	70.77	0	1415.25	3.14	11.80
zeros excluded	2126	20.01	77.41	1	1415.25	4.99	10.78
log fin. assets	2573	6.88	3.58	0	14.16	8.05	–0.98
zeros excluded	2126	8.32	1.86	0.69	14.16	8.52	–0.59
house equity	2611	40.29	72.57	–28.00	806.73	0	3.01
zeros excluded	1149	91.56	85.29	–28.00	806.73	72.40	2.33
log house equity	2611	4.49	5.75	–10.24	13.60	0	0.18
zeros excluded	1149	10.21	4.09	–10.24	13.60	11.19	–4.10
fin. equity	2528	14.71	72.21	–479.49	1415.25	2.66	11.14
zeros excluded	2171	17.13	77.65	–479.49	1415.25	4.04	10.33
log fin. equity	2528	5.13	6.16	–13.08	14.16	7.88	–1.26
zeros excluded	2171	5.97	6.26	–13.08	14.16	8.31	–1.72

Notes: for all variables, the first line refers to all observations for which the amount is not missing; the second line excludes both missings and zero amounts.

Definition of variables: house value: gross housing assets (in 1000 Dfl. or using the log–transformation, cf. fn. 5); house equity: value of the house net of outstanding mortgage debt; fin. assets: sum of the amounts held in saving account balances, time deposit accounts, saving certificates, certificates of deposit, shares in domestic and foreign companies, shares in investment funds, options, bonds and mortgage bonds; fin. equity: financial assets net of liabilities; skewness is measured as skewness$(x) \equiv \mathrm{E}(x - \mathrm{E}(x))^3/\sigma^3$, where σ^2 is the variance of x.

Table 3: Number of Observations per Regime

a value of the home vs. financial assets

number of observations (%)	financial assets > 0 (observed)	financial assets > 0 (missing)	financial assets $= 0$	sum
value of the home > 0 (observed)	regime (a) 1097 (37.98)	201 (6.96)	regime (b) 115 (3.98)	1413 (48.93)
value of the home > 0 (missing)	12 (0.42)	7 (0.24)	3 (0.10)	22 (0.76)
value of the home $= 0$	regime (c) 1017 (35.21)	107 (3.70)	regime (d) 329 (11.39)	1453 (50.31)
sum	2126 (73.61)	315 (10.91)	447 (15.48)	2888 (100.00)

b housing equity (net of mortgages) vs. financial equity (net of liabilities)

number of observations (%)	financial equity $\neq 0$ (observed)	financial equity $\neq 0$ (missing)	financial equity $= 0$	sum
housing equity $\neq 0$ (observed)	regime (a) 918 (31.79)	175 (6.06)	regime (b) 65 (2.25)	1158 (40.10)
housing equity $\neq 0$ (missing)	200 (6.93)	48 (1.66)	29 (1.00)	277 (9.59)
housing equity $= 0$	regime (c) 1055 (36.53)	137 (4.74)	regime (d) 261 (9.04)	1453 (50.31)
sum	2173 (75.24)	360 (12.47)	355 (12.29)	2888 (100.00)

Table 4: Estimation Results for Assets

	housing assets	selection eq.	financial assets	selection eq.
constant	11.668	–2.114	7.891	0.694
	(42.64)	(–3.27)	(5.09)	(1.15)
ln(income+1)	—	–0.218	–0.153	0.010
income $\leq$ 1200	—	(–3.11)	(–0.69)	(0.14)
ln(income+1)	—	0.482	0.278	0.298
income $\in$ (1200; 4400]	—	(3.78)	(1.20)	(1.59)
ln(income+1)	—	0.043	0.569	–0.337
income > 4400	—	(0.29)	(2.83)	(–1.64)
ln(max. rent subsidy+1)	—	–0.024	—	–0.065
	—	(–2.07)	—	(–4.23)
marginal tax rate	0.052	1.547	1.525	0.194
	(0.31)	(3.69)	(2.06)	(0.35)
age $\leq$ 35	–0.015	0.078	–0.001	0.005
	(–2.01)	(6.23)	(–0.07)	(0.46)
age $\in$ (35; 45]	0.019	–0.020	0.034	0.004
	(3.44)	(–1.96)	(2.31)	(0.37)
age > 45	–0.005	0.017	0.051	0.001
	(–2.10)	(3.69)	(6.85)	(0.12)
intermed. education	0.011	0.118	0.083	0.007
	(0.30)	(1.74)	(0.83)	(0.09)
high education	0.102	0.187	0.233	0.006
	(2.16)	(1.97)	(1.75)	(0.06)
self–employed	0.203	0.340	0.420	0.056
	(3.81)	(3.09)	(2.46)	(0.43)
white collar	0.028	0.097	–0.123	0.239
	(0.69)	(1.30)	(–1.06)	(2.51)
other occupation	0.009	0.098	0.229	0.343
	(0.16)	(0.92)	(1.52)	(3.12)
part time	0.174	–0.229	–0.432	0.105
	(2.63)	(–1.78)	(–2.45)	(0.75)
other labor	0.064	–0.327	–0.435	–0.004
	(1.24)	(–3.32)	(–3.26)	(–0.03)
female	0.104	–0.034	–0.259	0.232
	(1.88)	(–0.31)	(–1.72)	(2.21)
couple	0.113	0.247	–0.046	–0.003
	(1.93)	(2.21)	(–0.27)	(–0.03)
divorced / widows	0.170	–0.059	–0.060	–0.410
	(2.59)	(–0.48)	(–0.32)	(–3.31)
number of children	0.019	0.052	–0.095	0.169
	(1.21)	(1.72)	(–1.97)	(4.96)
house price index	0.510	–0.389	0.832	–0.699
	(5.30)	(–2.14)	(3.12)	(–3.36)

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Table 4: *continued*

	housing assets	selection equation	financial assets	selection equation
bigger cities	0.034	0.200	—	0.318
	(0.42)	(1.37)	—	(2.11)
smaller cities	0.089	0.226	—	0.319
	(1.14)	(1.53)	—	(2.08)
country towns	0.188	0.111	—	0.300
	(2.55)	(0.80)	—	(2.09)
country side	0.256	0.102	—	0.445
	(3.07)	(0.66)	—	(2.65)
		correlation matrix		
housing assets	1	.	.	.
	—	.	.	.
selection equation	–0.831	1	.	.
	(–5.46)	—	.	.
financial assets	–0.013	0.034	1	.
	(–0.09)	(0.23)	—	.
selection equation	0.165	0.195	–0.610	1
	(1.09)	(1.28)	(–4.00)	—
σ	0.555	1.000	1.791	1.000
	(55.59)	(fixed)	(56.08)	(fixed)
λ_1		0.031		
		(2.73)		
λ_2		–0.013		
		(–0.48)		
log likelihood		–42033.95		
number of obs.		2888		

note: t–values in parentheses; cf. Tables 1 and 2 for definition of variables

Table 5: Estimation Results for Equities

	housing equity	selection eq.	financial equity	selection eq.
constant	10.133	–2.358	10.749	0.744
	(3.77)	(–3.58)	(0.94)	(1.18)
ln(income+1)	—	–0.238	–0.528	0.060
income ≤ 1200	—	(–3.34)	(–0.32)	(0.85)
ln(income+1)	—	0.487	–0.950	0.448
income $\in (1200; 4400]$	—	(3.11)	(–1.26)	(2.09)
ln(income+1)	—	–0.085	0.009	–0.321
income > 4400	—	(–0.52)	(0.01)	(–1.47)
ln(max. rent subsidy+1)	—	–0.023	—	–0.074
	—	(–1.57)	—	(–4.24)
marginal tax rate	–0.191	1.969	3.127	–0.219
	(–0.11)	(4.31)	(1.32)	(–0.35)
age ≤ 35	–0.039	0.080	–0.030	0.008
	(–0.69)	(6.43)	(–0.57)	(0.58)
age $\in (35; 45]$	0.195	–0.025	0.053	0.008
	(3.95)	(–2.48)	(1.12)	(0.59)
age > 45	0.037	0.017	0.158	–0.007
	(0.60)	(3.55)	(4.76)	(–1.30)
intermed. education	0.117	0.099	–0.037	–0.070
	(0.37)	(1.44)	(–0.11)	(–0.79)
high education	0.727	0.176	0.056	–0.073
	(1.71)	(1.81)	(0.13)	(–0.59)
self–employed	–0.138	0.328	0.535	0.064
	(–0.24)	(2.82)	(0.90)	(0.45)
white collar	–0.981	0.128	–0.576	0.350
	(–2.18)	(1.67)	(–1.41)	(3.38)
other occupation	–0.014	0.137	0.411	0.329
	(–0.01)	(1.28)	(0.63)	(2.80)
part time	0.463	–0.268	–1.624	–0.074
	(0.38)	(–2.01)	(–2.74)	(–0.49)
other labor	–0.427	–0.328	–1.267	0.054
	(–0.58)	(–3.23)	(–2.27)	(0.44)
female	–0.004	–0.038	1.575	0.109
	(–0.01)	(–0.34)	(2.50)	(0.95)
couple	1.668	0.297	0.362	–0.030
	(3.38)	(2.44)	(0.60)	(–0.22)
divorced / widows	1.560	–0.030	–1.477	–0.402
	(1.86)	(–0.23)	(–2.01)	(–2.99)
number of children	0.060	0.062	–0.159	0.219
	(0.33)	(1.98)	(–1.05)	(6.19)
house price index	0.112	–0.348	–1.136	–0.582
	(0.12)	(–1.91)	(–1.26)	(–2.53)

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Table 5: *continued*

	housing equity	selection equation	financial equity	selection equation
bigger cities	–1.725	0.287	—	–0.003
	(–1.07)	(1.87)	—	(–0.01)
smaller cities	–1.447	0.296	—	–0.044
	(–0.89)	(1.90)	—	(–0.23)
country towns	–1.045	0.146	—	–0.039
	(–0.65)	(0.99)	—	(–0.22)
country side	–0.444	0.168	—	0.077
	(–0.26)	(1.03)	—	(0.37)
		correlation matrix		
housing equity	1	·	·	·
	—	·	·	·
selection equation	0	1	·	·
	—	—	·	·
financial equity	0.166	0	1	·
	(2.09)	—	—	·
selection equation	0	0.214	0	1
	—	(2.69)	—	—
σ	3.962	1.000	6.089	1.000
	(42.14)	(fixed)	(34.72)	(fixed)
λ_1		0.004		
		(0.02)		
λ_2		–0.096		
		(–2.84)		
loglikelihood		–43648.30		
number of obs.		2888		

note: t–values in parentheses; cf. Tables 1 and 2 for definition of variables

Figure 1: Marginal Distributions of Assets, Continuous Parts

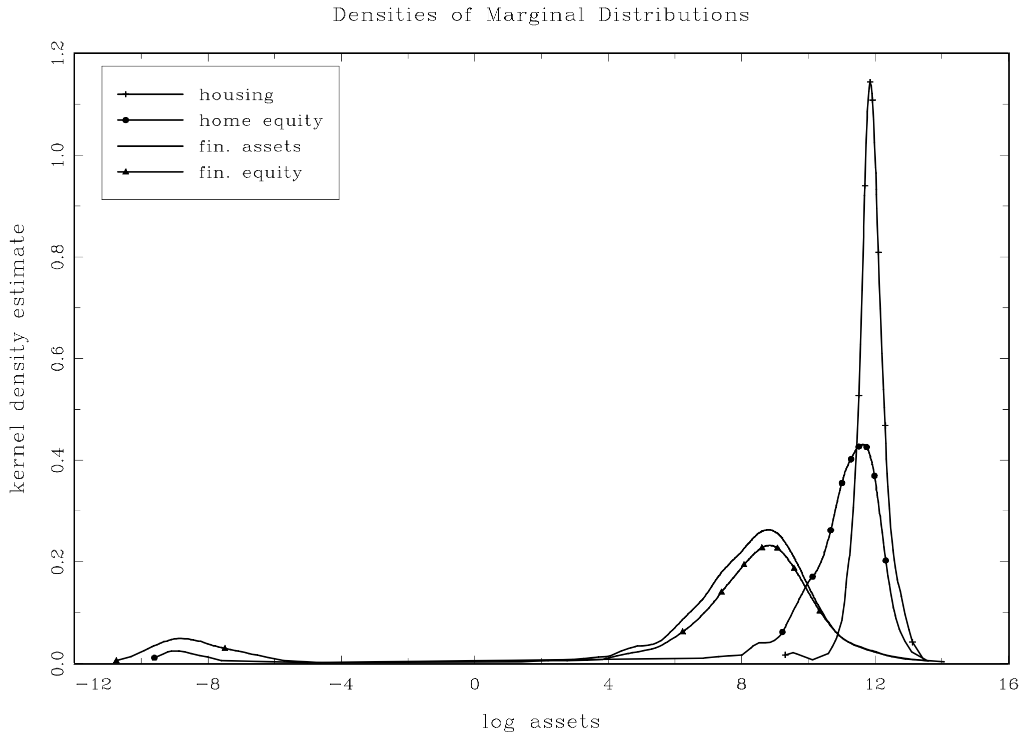


Figure 2: Ownership Rates

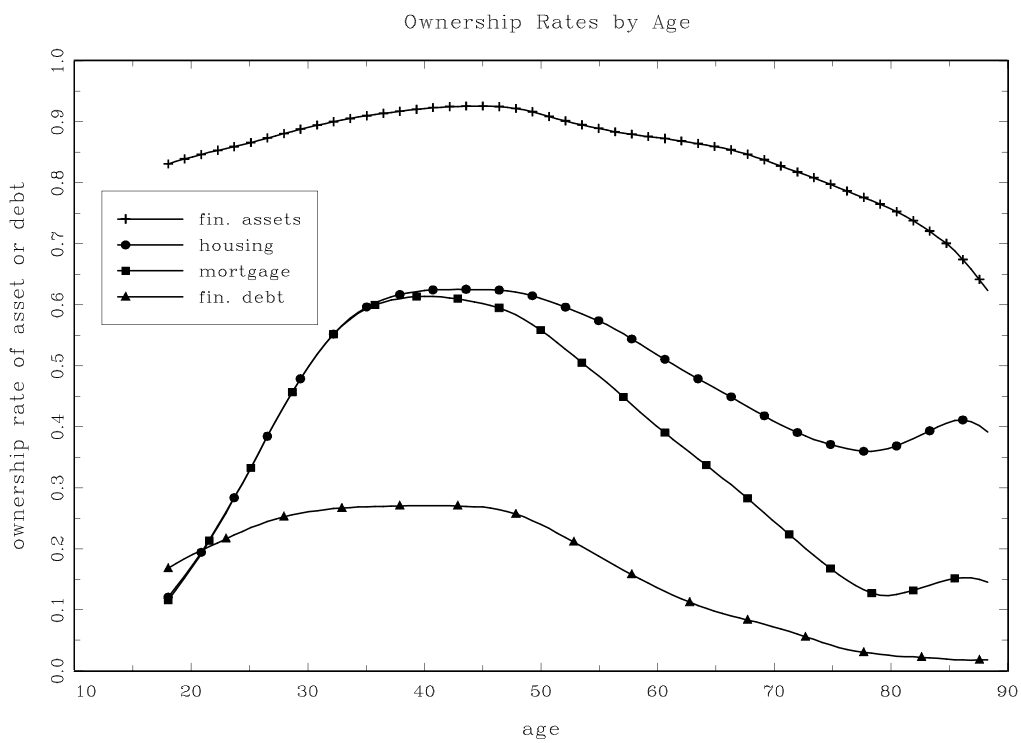


Figure 3: Wealth Holding

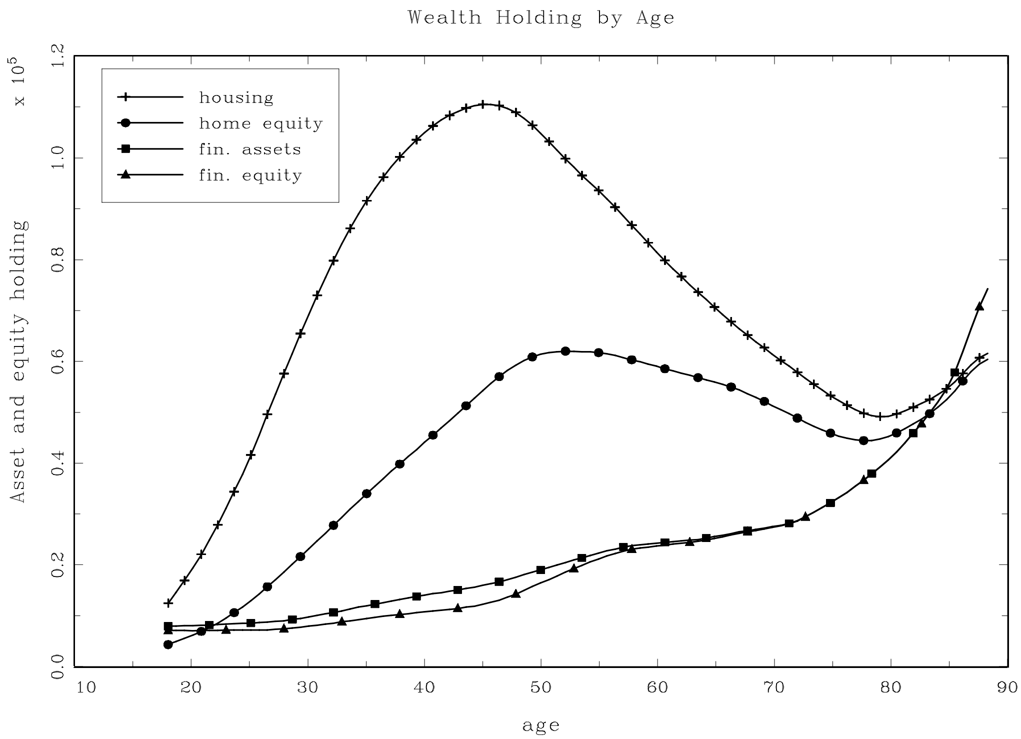
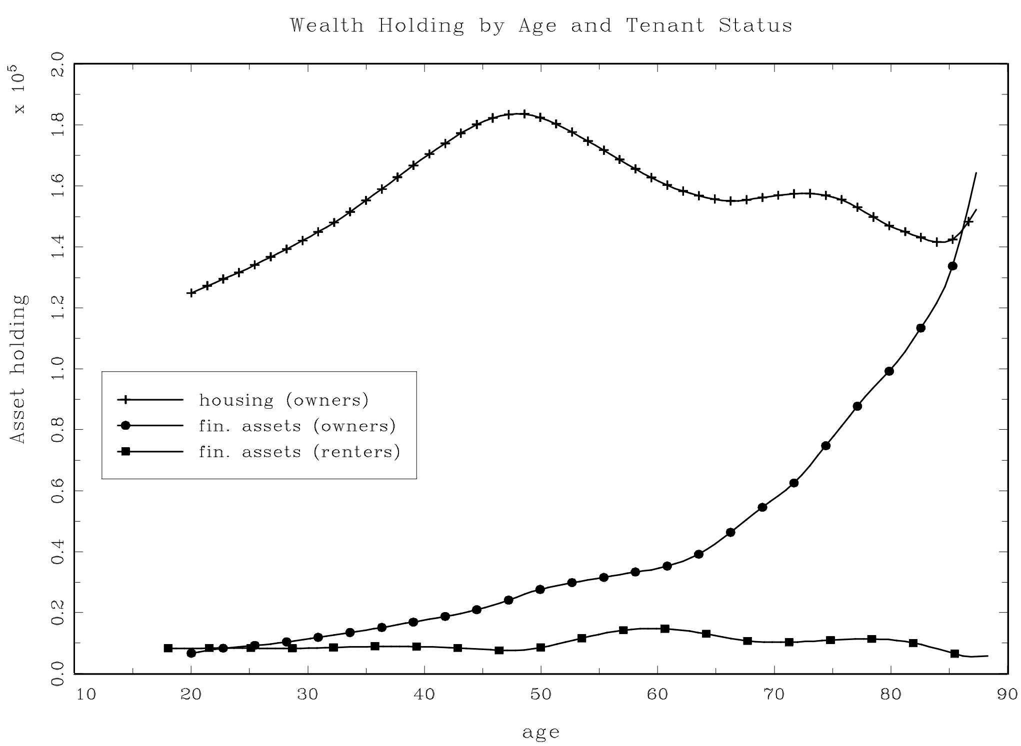


Figure 4: Wealth Holding by Tenant Status



A Coherency of Empirical Model

In this appendix we address coherency of the empirical model. For ease of exposition, we first assume that the thresholds are zero, i.e. the case of nonnegativity constraints. The model we consider is thus given by

$$\begin{array}{ll} (a) & y_1^* > 0, y_2^* > 0 : \\ & y_1 = y_1^*; \qquad y_2 = y_2^* \\ \\ (b) & \tilde{y}_1 > 0, y_2^* < 0 : \\ & y_1 = \tilde{y}_1 = y_1^* + \lambda_1 y_2^*; \qquad y_2 = 0 \\ \\ (c) & y_1^* < 0, \tilde{y}_2 > 0 : \\ & y_1 = 0; \qquad y_2 = \tilde{y}_2 = y_2^* + \lambda_2 y_1^* \\ \\ (d) & \tilde{y}_1 < 0, \tilde{y}_2 < 0 : \\ & y_1 = 0; \qquad y_2 = 0. \end{array} \tag{A.1}$$

(1) implies that the (y_1^*, y_2^*) follow a continuous distribution with support $\mathbf{R}^2$. Coherency therefore means that the set of (y_1^*, y_2^*) which yield no or more than one solution of (A.1) should have measure zero. Sixteen cases can be distinguished, according to whether y_1^*, y_2^*, $\tilde{y}_1$, and $\tilde{y}_2$ are positive or negative. Twelve cases lead to exactly one solution, for one of the four regimes $(a) - (d)$. In four cases, the solution is either nonunique or nonexistent:

- If $y_1^* > 0$, $y_2^* > 0$, $\tilde{y}_1 < 0$, and $\tilde{y}_2 < 0$, regimes (a) as well as (d) would yield a solution.
- If $y_1^* < 0$, $y_2^* < 0$, $\tilde{y}_1 > 0$, and $\tilde{y}_2 > 0$, (b) as well as (c) yield a solution.
- If $y_1^* > 0$, $y_2^* < 0$, $\tilde{y}_1 < 0$, and $\tilde{y}_2 > 0$ or
- if $y_1^* < 0$, $y_2^* > 0$, $\tilde{y}_1 > 0$, and $\tilde{y}_2 < 0$, none of the regimes leads to a solution.

Coherency thus means that λ_1 and λ_2 must be such that these four cases do not occur. These four cases are those for which both y_1^* and $\tilde{y}_1$ and y_2^* and $\tilde{y}_2$ have different signs.

Proposition: Model (A.1) is coherent if and only if $\lambda_1 \lambda_2 \leq 1$.

Proof: Suppose the model is not coherent. Then the argument given above implies that there are y_1^*, y_2^*, $\tilde{y}_1$ and $\tilde{y}_2$ such that

$$y_1^*(y_1^* + \lambda_1 y_2^*) < 0 \quad \text{and} \quad y_2^*(y_2^* + \lambda_2 y_1^*) < 0.$$

This implies

$$\lambda_1 y_1^* y_2^* < -y_1^{*2} < 0 \quad \text{and} \quad \lambda_2 y_1^* y_2^* < -y_2^{*2} < 0.$$

The product of these inequalities is

$$\lambda_1 \lambda_2 y_1^{*2} y_2^{*2} > y_1^{*2} y_2^{*2},$$

which implies

$$\lambda_1 \lambda_2 > 1.$$

For the reverse implication, assume that $\lambda_1 \lambda_2 > 1$. Distinguish two cases: $\lambda_1 > 0$ and $\lambda_2 > 0$ and $\lambda_1 < 0$ and $\lambda_2 < 0$. Consider the first case. In this case,

$$-\lambda_2 < -\frac{1}{\lambda_1},$$

so that the set of (y_1^*, y_2^*) with $y_1^* > 0$ and $-\lambda_2 y_1^* < y_2^* - \frac{1}{\lambda_1} y_1^*$ has nonzero measure. This is the set for which $y_1^* > 0$, $y_2^* < 0$, $\tilde{y}_1 < 0$, and $\tilde{y}_2 > 0$. Thus the model is incoherent. Similarly, for the other case ($\lambda_1 < 0$ and $\lambda_2 < 0$), the set with $y_1^* > 0$, $y_2^* > 0$, $\tilde{y}_1 < 0$, and $\tilde{y}_2 < 0$ has nonzero measure. Thus $\lambda_1 \lambda_2 > 1$ implies incoherency. This completes the proof. •

Now consider the case with thresholds. If we use (4) and rewrite the model as (5) and (6), the coherency requirement remains exactly the same as above. Just replace y_i^* with $S_i^* (i = 1, 2)$. It is not intuitively clear, however, why (4) would be appropriate. A more general specification would be

$$\begin{aligned} \tilde{T}_1 &= T_1^* + \mu_1 T_2^* \\ \tilde{T}_2 &= T_2^* + \mu_2 T_1^* \end{aligned}$$

for arbitrary μ_1 and μ_2. With $S_i^* = y_i^* - T_i^*$ and $\tilde{S}_i$ as in (5), the regime allocation equations for this model are given by

$$\begin{aligned} &(a) \quad S_1^* > 0, S_2^* > 0 \\ &(b) \quad \tilde{S}_1 + (\lambda_1 - \mu_1) T_2^* > 0, S_2^* < 0 \\ &(c) \quad S_1^* < 0, \tilde{S}_2 + (\lambda_2 - \mu_2) T_1^* > 0 \\ &(d) \quad \tilde{S}_1 + (\lambda_1 - \mu_1) T_2^* < 0, \tilde{S}_2 + (\lambda_2 - \mu_2) T_1^* < 0 \end{aligned}$$

As before, we can distinguish 16 cases, according to the signs of S_1^*, S_2^*, $\tilde{S}_1 + (\lambda_1 - \mu_1) T_2^*$, and $\tilde{S}_2 + (\lambda_2 - \mu_2) T_1^*$. To guarantee a unique solution, λ_1, λ_2, μ_1 and μ_2 should be such that the four cases are excluded for which the signs of S_1^* and $\tilde{S}_1 + (\lambda_1 - \mu_1) T_2^*$, as well as the signs of S_2^* and $\tilde{S}_2 + (\lambda_2 - \mu_2) T_1^*$ are different. The main difference with the situation we had before, however, is that these quantities are not determined by two but by four latent variables. It seems reasonable to assume that the support of $(S_1^*, S_2^*, T_1^*, T_2^*)$ equals $\mathbf{R}^4$. Then coherency can only be obtained if $\lambda_1 = \mu_1$ or $\lambda_2 = \mu_2$. This shows that a substantially more general model than the one defined by (4) cannot be obtained. For example, the intuitively attractive model with $\mu_1 = \mu_2 = 0$ (thresholds not affected by the regime switch) is only coherent if $\lambda_1 = 0$ or $\lambda_2 = 0$.